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Conclusions: The MWA framework remains a working prototype (proof of principle); however, it can readily be used to construct and experiment with different types of physiologic signal display. Possible applications of MWA include clinical research, education, patient safety, and quality control.

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Using "off-the-shelf" tools for terabyte-scale waveform recording in intensive care unit: Computer system design, database description, and lessons learned

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Objectives: Until now, the creation of massive (long-term and multichannel) waveform databases in intensive care required an interdisciplinary team of clinicians, engineers, and informaticians and, in most cases, also design-specific software and hardware development. Recently, several commercial software tools for waveform acquisition became available. Although commercial products and even turnkey systems are now being marketed as simple and effective, the performance of those solutions is not known. The additional expense upfront may be worthwhile if commercial software can eliminate the need for custom software and hardware systems and the associated investment in teams and development.
Methods: We report the development of a computer system for long-term, large-scale recording and storage of multichannel physiologic signals that was built using commercial solutions (software and hardware) and existing hospital IT infrastructure.
Results: Both numeric (1 Hz) and waveform (62.5-500 Hz) data were captured from 24 SICU bedside monitors simultaneously and stored in a file-based vital sign data bank (VSDB) during 1-year period (total DB size is 4.21 TB). In total, physiologic signals were recorded from 1175 critically ill patients. Up to 6 electrocardiographic leads, all other monitored waveforms, and all monitored numeric data were recorded in most of the cases. Several data sets from our VSDB are available online (www.burykin.com/sbt/), and more will be uploaded on "PhysioNet Works" (http://physionet.org/data-sharing/).
Conclusions: We describe the details of the building blocks of our system, provide description of 3 data sets exported from our VSDB, and compare the contents of our VSDB with other available waveform databases. Finally, we summarize lessons learned during recording, storage, and preprocessing of physiologic signals.

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Stochastic analysis of heart rate variability: Respiration asymmetry and echocardiographic parameters

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Objectives: Human heart rate is moderated by the autonomous nervous system. One of the dominant factors that determine the heart rate in physiologic conditions is its coupling with the respiratory rhythm. Using the language of stochastic processes, we analyzed both rhythms simultaneously, taking the data from polysomnographic recordings of 2 healthy individuals.
Methods: Each rhythm was treated as a sum of a deterministic drift term and a diffusion term (the first 2 terms of the Kramers-Moyal expansion). We found that normal heart rate variability may be considered the result of a bidirectional coupling of 2 nonlinear oscillators: the heart itself and the respiratory system. On average, the diffusion (or noise) component measured is comparable in magnitude to the oscillatory (deterministic) term for both signals investigated. In a separate study, the Kramers-Moyal expansion was applied to the heart rate variability of 10 healthy males (age, 26 −4/+3 years) and 49 patients with hypertrophic cardiomyopathy (HCM) (25 males, 24 females; age, 29.5 −11.5/+10.5 years). The drift and diffusion terms may be used for a stochastic reconstruction of time series and for a description of the properties of the heart rate variability of nighttime recordings.
Results: New parameters characterizing the diffusion term were introduced: the coefficients of the linear fit to the left (LCF) and right (RCF) branches of the dependence of the diffusion term on a rescaled heart rate. Relations of the new parameters to classical echocardiography parameters were studied. Using the relation between the difference LCF-RCF and the left ventricular systolic diameter, the patients with HCM studied were divided into 3 groups. In addition, the comparison of the properties of the heart rate variability in the HCM group with that obtained for the healthy young men showed that the parameter LCF-RCF may be treated as a measure of the effect of HCM on heart rate variability and may have diagnostic value.
Conclusions: An asymmetry of heart rate variability was obtained, which is related to the acceleration and deceleration ability of heart rhythm. The Kramers-Moyal expansion may be useful for medical diagnostics providing information on the relation between respiration and heart rate variability. This interaction is mediated by the autonomous nervous system, including the baroreflex, and results in a commonly observed phenomenon—respiratory sinus arrhythmia, which is typical for normal subjects and often impaired by pathology.

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Lyapunov exponent calculations as independent indices of complexity of cardiovascular regulation during hemorrhage with autonomic blockade

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Objectives: The largest Lyapunov exponent (LLE) is a standard method used to characterize the level of chaos in complex physiologic systems such as the cardiovascular system. Previously, we showed that LLE calculated in beat domain remains positive during lethal hemorrhagic shock (HS). We sought to evaluate the utility of LLE and the asymptote of the divergence curve (AS) for monitoring of subjects in time domain using data from a swine model of severe pump-controlled HS. The AS denotes the average Euclidean divergence distance between adjacent orbits of the attractor.

Methods: Ten midazolam-sedated, spontaneously breathing, sexually mature swine underwent a controlled HS protocol with removal of 60% of blood volume in 1 hour. Controls (n = 4) received HS alone. Vagal blockade group (n = 3) received atropine 0.005 mg/kg then 0.5 mg/min continuous rate infusion and HS. Sympathetic blockade (n = 3) group received propranolol 0.5 mg/kg then 1 mg/min and HS. EKG was recorded at 500 Hz and the R-R intervals (RRI) were calculated. The LLE and AS were calculated using Rosenstein's method with an embedding factor of 2 and a delay of 4 over a set of 1024 consecutive RRI samples taken at baseline and HS. The RRI time series was then resampled at 20 Hz to move the LLE calculations from the beat domain to the time domain. Data are medians. Statistics were performed by 1-way analysis of variance and post hoc analysis.
Results: See Table.

Table

Time point/ variables	Group	RRI	LLE	AS	Post hoc
Baseline	Control	883	1.70	3.67	$P < .05$
	Vagal block	384	1.79	0.28	
	Sympathetic block	1057	1.65	4.69	
During HS	Control	839	1.68	3.65	$P < .05$
	Vagal block	336	2.12	0.23	
	Sympathetic block	1137	1.45	4.37	
	ANOVA	$P < .001$	ns	$P < .001$	

Conclusions: The LLE remained positive in every condition, signifying presence of deterministic chaotic trends during HS and HS with branch-specific autonomic blockade. The AS was the lowest after vagal blockade, distinguishing it from sympathetic blockade and baseline. The simplest attractors are associated with vagal blockade and HS and feature low AS, which denotes the degree of constraint of the system in phase space. The AS provides useful additional information to LLE in assessment of complexity of cardiovascular regulation during HS.

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Locating consensus QRS peaks confounded by multiple noisy electrocardiographic leads

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Objectives: Precise measures of R-R intervals (and, therefore, QRS peaks) are essential for accurate heart rate complexity analysis. Noise and artifact confound peak identification algorithms. Several clinical settings (stress tests, intensive care unit care) facilitate multiple lead data. We, therefore, sought a strategy to leverage multiple leads to reduce the uncertainty of peak location in noisy data sets.
Methods: Using a set of 12-lead electrocardiograms from 149 exercise stress tests and 81 dobutamine stress tests, 3 strategies were used to identify consensus fiducial points. The filter bank QRS detection method was used in each case. The strategies were (1) averaged: all 12 leads were averaged, and the resulting data was run through a QRS detector; (2) denoised and averaged: the 12 leads were individually denoised using the Hilbert-Huang transform and then averaged; and (3) maximum agreement: the 12 leads were initially processed through the QRS detector individually, and QRS peaks were recorded. We then classified a QRS peak if and only if 7 of the leads agreed a peak occurred within 10 milliseconds. All analyses were performed using MATLAB.
Results: The maximum agreement method correctly detected the QRS peaks using aggregate data, whereas the first 2 methods commonly recorded peaks that did not occur or else skipped a beat.
Conclusions: Consensus strategies may be important to identifying QRS locations where multiple-lead data are available. Iterative optimization (consensus reciprocal to a palette of peak detection methods) may have additional value in locating and identifying R waves in clinical data contaminated by noise.

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Structured physiologic and ethnographic data identify rules governing red blood cell transfusion practices in critical care

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Objectives: Although red blood cell (RBC) transfusions can augment oxygen delivery, they also increase risk of infectious and ischemic postoperative morbidity and mortality, lengthen intensive care unit (ICU) stays, and inflate overall costs. Multispecialty consensus guidelines attempt to balance those benefits, risks, and costs for perioperative and postoperative RBC transfusions of cardiac surgery patients. To assess and subsequently optimize RBC use, we combined directed ethnography with physiologic data toward analysis of decisions leading to "unique transfusion events" in 2 surgical ICUs.
Methods: A unique transfusion event was defined as a decision to transfuse RBCs, insensitive to the reason or RBC volume. The directed ethnography involved systematic observation of all activities in the ICUs including contextual information, verbal and nonverbal behaviors, use of artifacts, and observer impressions. From these observations, we captured the discussion about each patient, current laboratory values including the hemoglobin level, the recap of patient status based on system, and the decision to transfuse or not to transfuse. Field notes were collected over 45 clinical days by a single individual who had received 20 hours of training from experienced ethnographers and cognitive linguists. Categories for coding the observations were developed using grounded theory. In addition, the investigator and an experienced ethnographer coded the same notes to assess and ensure interrater reliability.
Results: Analysis of the field notes yielded 25 categories of behaviors, gestures, and patterns of communication for 140 unique transfusion events. Each category was given an operational